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(71) Applicant: ILLINOIS SUPERCONDUCTOR CORPORATION [US/US]; 451 Kingston Court, Mt. Prospect, IL 60056 (US).

(72) Inventors: ABDELMONEM, Amr; Apartment 106, 2754 Buffalo Grove Road, Arlington Heights, IL 60004 (US). REMILLARD, Stephen, K.; 1401 Rand Road, Arlington Heights, IL 60004 (US). GOLANT, Benjamin; 795 Oak Court, Crystal Lake, IL 60014 (US).

(74) Agent: GERSTEIN, Robert, M.; Marshall, O'Toole, Gerstein, Murray & Borun, 6300 Sears Tower, 233 S. Wacker Drive, Chicago, IL 60606 (US).

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(54) Title: CDMA COMMUNICATION SYSTEM HAVING A HIGHLY SELECTIVE FILTER

(57) Abstract: A communication system includes a communication device and a base station in RF communication with the communication device in accordance with a code-based modulation scheme, such as W-CDMA. A highly selective filter is included in a receive path of the base station to improve performance in both uplink and downlink signals transmitted during the RF communication. The base station has an antenna for receiving the uplink signal, which is then provided to the highly selective filter for selection of a desired frequency band. A low-noise amplifier couples the highly selective filter to a demodulator responsive to signals modulated in accordance with the code-based modulation scheme. The demodulator is part of a data processing module to which the low-noise amplifier may be directly connected. The improved performance includes a reduction in power control messaging on the downlink signal, a reduction in a power level associated with the transmission of the uplink signal from the communication device, and an increase in both downlink and uplink capacity.

CDMA COMMUNICATION SYSTEM HAVING A HIGHLY SELECTIVE FILTER

FIELD OF THE INVENTION

The present invention relates generally to wireless communication systems and, more particularly, to such systems utilizing code-based modulation schemes such as CDMA.

BACKGROUND OF THE INVENTION

Radio frequency (RF) receivers for wireless communication stations must provide high degrees of both selectivity (the ability to distinguish between signals separated by small frequency differences) and sensitivity (the ability to receive weak signals). In a typical base station, an incoming RF signal is first passed through a low loss, RF bandpass filter to remove signal components outside of the frequency range of the desired signal. Because the resulting filtered signal is usually very weak, the signal is coupled to an amplifier that does not introduce a significant amount of noise (*i.e.*, a low-noise amplifier or LNA).

As the number of wireless telephone carriers per region has grown to accommodate large increases in subscriber demand, the resulting congestion within the RF spectrum has put a premium on high selectivity. In addition, new digital modulation methods such as code division multiple access (CDMA) have been devised to make more efficient use of the crowded RF spectrum to increase capacity (*i.e.*, the maximum number of simultaneous users, or aggregate data throughput for a set number of users, per cell site). These digital technologies have supplied wireless service providers with the ability to provide greater security and advanced personal communications system (PCS) features to their subscribers. Digital systems utilizing, for

example, CDMA technology, require a broader channel bandwidth to operate efficiently. The increased breadth of each channel, in turn, makes it more difficult to avoid signal distortion in connection with, for example, envelope delay and ripple. Conventional filters may have difficulties addressing these challenges while still providing high selectivity because higher selectivity typically results in higher insertion loss which, in turn, may impact service quality.

The relatively recent advancements in superconducting technology have given rise to a new type of RF filter, namely, the high-temperature, superconducting (HTS) filter. HTS filters contain components that act as superconductors at or above the liquid nitrogen temperature of 77K. Such filters provide greatly enhanced performance in terms of both sensitivity and selectivity over conventional (*i.e.*, non-superconducting) filters. Specifically, HTS filters have been shown to provide excellent rejection with signal losses much lower than that possible using conventional filters. These improvements in selectivity without higher insertion losses have generally allowed wireless telephone carriers to increase the range of each base station. As long as the system remains within its capacity, the increased range will result in an increase in the minutes of use (MOUs).

However, these performance enhancements have been gained at the cost of a more complicated system of components in each RF receiver. More particularly, HTS filters must be accompanied by a cooling system to ensure the filters are maintained at relatively low temperatures (*e.g.*, approximately 90K or lower).

In order to maintain the devices at such temperatures, the cooling system includes some type of cryorefrigerator. The cryorefrigerator typically includes a compressor for maintaining a supply of pressurized coolant and a heat exchanger or cold head to remove heat from the devices

being cooled. In addition, an HTS filter must minimize the amount of heat transfer from the environment by enclosing the cooled devices in a cryostat. The cryostat is then often evacuated of any gaseous material to reduce convection heating.

FIG. 1 shows a prior art CDMA base station having a primary antenna 10 and a diversity antenna 12 coupled to a cabinet 14. The primary antenna 10 is designed for both transmission and reception of RF signals near either 800 MHz (cellular) or 1.9 GHz (PCS), while the diversity antenna 12 is dedicated to a diversity receive path of either band. The antenna 10 is coupled to components disposed within the walls of the cabinet 14 and associated with both a primary receive path and a transmit path, while the diversity antenna 12 is coupled to the diversity receive path, which includes a conventional bandpass filter 16 and a non-cryogenic, low-noise amplifier 18. After the antenna 10, the primary receive path includes a conventional bandpass filter (not shown) disposed within a conventional duplexer 20 and an additional non-cryogenic, low-noise amplifier 22. The conventional duplexer 20 further includes a conventional transmit filter (not shown) coupled to the antenna 10 as part of the transmit path.

The transmit path begins with transmit CDMA processing circuitry 22 dedicated to generating CDMA-modulated transmit signals on a line 24 coupled to a linear power amplifier 26. The CDMA-modulated signal is amplified by the linear power amplifier 26 and provided to the conventional duplexer 20 for filtering in preparation for transmission via the antenna 10. In theory, the conventional transmit filter is provided to block noise generated by the linear power amplifier 26 in the passband of the receive filter of the base station as well as other nearby stations. This noise, sometimes called spectral regrowth in CDMA systems, may raise the noise floor of the primary and diversity receive paths to an extent that limits the

capability of receive CDMA processing circuitry 28 to demodulate and otherwise process the RF signals uplinked to and received by the base station.

SUMMARY OF THE INVENTION

In accordance with one aspect of the present invention, a communication station having an antenna for receiving a communication signal modulated in accordance with a code-based modulation scheme includes a highly selective filter having an input and an output wherein the input is coupled to the antenna, a low-noise amplifier coupled to the output of the highly selective filter, and a demodulator coupled to the low noise amplifier and responsive to signals modulated in accordance with the code-based modulation scheme.

In a preferred embodiment, the code-based modulation scheme is CDMA and the highly selective filter includes a high-temperature superconducting component. The low-noise amplifier may be a non-cryogenic amplifier or may be disposed in a cryostat. The communication station preferably further includes a transmission filter coupled to the antenna and the transmission filter may be a non-superconducting filter.

In another preferred embodiment, the demodulator is part of a data processing module and the low-noise amplifier is directly connected to the data processing module.

The highly selective filter may have an additive noise contribution of about no more than 1 dB, and include no less than ten poles for a bandwidth of no less than about 1%, or include no less than five poles for a bandwidth of no greater than about 0.3%. The code-based modulation scheme may be W-CDMA.

In yet another preferred embodiment, the communication station is combined with a communication device in RF communication therewith via an uplink signal transmitted from the communication device and a downlink signal transmitted to the communication device. The downlink signal includes power control messaging determinative of a power level of the uplink signal. The reception of the uplink signal via the highly selective filter reduces the power control messaging, while reception of the uplink signal via the highly selective filter reduces the power level of the communication device.

The communication station may be combined with an additional communication device in RF communication with the communication station utilizing channel capacity made available by the reduced power control messaging. Reception of the uplink signal via the highly selective filter increases capacity for receiving a further uplink signal associated with the additional communication device.

In accordance with another aspect of the present invention, a communication station having an antenna for receiving a communication signal modulated in accordance with a code-based modulation scheme includes a filter having an input and an output wherein the input is coupled to the antenna, and the filter includes a high-temperature superconducting component. The communication station further includes a low-noise amplifier coupled to the output of the highly selective filter, and a demodulator coupled to the low-noise amplifier and responsive to signals modulated in accordance with the code-based modulation scheme.

The code-based modulation scheme may be CDMA, while the low-noise amplifier may be a non-cryogenic amplifier or disposed in a cryostat. The communication station may include a transmission filter coupled to the antenna, and the transmission filter may be a non-superconducting filter.

Preferably, the demodulator is part of a data processing module, and the low-noise amplifier is directly connected to the data processing module.

In accordance with yet another aspect of the present invention, a communication station having an antenna for receiving a communication signal modulated in accordance with a code-based modulation scheme includes a highly selective filter having an input and an output wherein the input is coupled to the antenna, a low-noise amplifier coupled to the output of the highly selective filter to develop an amplified and filtered communication signal, and a demodulator coupled to the low noise amplifier and responsive to signals modulated in accordance with the code-based modulation scheme. The amplified and filtered communication signal is provided to the demodulator without further significant RF selection filtering.

In accordance with still another aspect of the present invention, a communication system includes a communication device and a base station in RF communication with the communication device in accordance with a code-based modulation scheme. The base station includes a highly selective filter in a receive path.

The highly selective filter preferably includes a high-temperature superconducting component, and the base station further may include a non-cryogenic low-noise amplifier or a low-noise amplifier and a cryostat in which the low-noise amplifier is disposed. The base station may further include a transmission filter and an antenna, and the highly selective filter in the receive path and the transmission filter are coupled to the antenna. The transmission filter may be a non-superconducting filter. The highly selective filter in the receive path may be directly connected to the antenna.

In another preferred embodiment, the RF communication between the base station and the communication device includes a downlink signal transmitted by the base station and an uplink signal received by the base station, and the downlink signal has a pilot channel for transmitting power control messaging to control a power level of the communication device. Reception of the uplink signal via the highly selective filter then reduces the power control messaging on the pilot channel, and reduces the power level of the communication device. The communication system may include an additional communication device in RF communication with the communication station utilizing channel capacity made available by the reduced power control messaging. Reception of the uplink signal via the highly selective filter stabilizes a signal strength of the downlink signal as received at the first-named communication device over a range of RF communication distances.

In a preferred embodiment, the communication device is one of a plurality of communication devices in RF communication with the base station, the base station includes a transmitter such that the RF communication includes a downlink, the base station has a downlink capacity for transmitting signals to the plurality of communication devices, and the highly selective filter in the receive path increases the downlink capacity.

In accordance with another aspect of the present invention, a method of improving performance of a communication station having a receive path includes the steps of establishing RF communication between a plurality of communication devices and the communication station in accordance with a code-based modulation scheme, modifying the communication station by replacing a first filter of the communication station with a second, highly selective filter having a selectivity higher than the first filter, and

establishing improved RF communication between the plurality of communication devices and the modified communication station.

The highly selective filter preferably includes a high-temperature, superconducting component, and the code-based modulation scheme is preferably CDMA.

The communication station may include a transmit path, and the RF communication may include a downlink signal that passes through the transmit path and an uplink signal that passes through the receive path. The improved RF communication then includes increased capacity for both the uplink signal and the downlink signal. The downlink signal may include a pilot channel for transmitting power control messaging to control a power level of a certain device of the plurality of communication devices such that the improved RF communication includes a reduction in the power control messaging on the pilot channel. The improved RF communication also includes a reduction in the power level of the certain device of the plurality of communication devices.

The downlink signal may have a signal strength as received at the certain device of the plurality of communication devices, and the improved RF communication includes a stabilization of the signal strength over a range of RF communication distances.

Other features and advantages are inherent in the communication stations and systems claimed and disclosed or will become apparent to those skilled in the art from the following detailed description in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a prior art CDMA base station;

FIG. 2 is a schematic representation of a portion of a wireless communication system in which a base station processes calls from a number of communication devices in accordance with one aspect of the present invention;

FIG. 3 is a simplified block diagram of the base station of FIG. 2 depicting in greater detail those components directed to CDMA signal processing in accordance with one aspect of the present invention;

FIG. 4 is a block diagram of a front end of the CDMA components of FIG. 3 in accordance with another aspect of the present invention;

FIG. 5A is a screen capture of a test unit display of channel use and power during a capacity test of the prior art CDMA base station of FIG. 1;

FIG. 5B is a screen capture of a test unit display of channel use and power during a capacity test of the base station in accordance with the present invention;

FIG. 6 is a plot of mobile transmit power (MTX) of a test communication device as a function of distance from both the prior art CDMA base station of FIG. 1 as well as the base station in accordance with the present invention;

FIG. 7 is a plot of a received signal strength indicator (RSSI) of a test communication device received signal strength as a function of distance from both the prior art CDMA base station of FIG. 1 as well as the base station in accordance with the present invention; and

FIG. 8 is a plot of a signal bit energy to noise floor ratio (E_c/I_o) of a pilot channel as received by a test communication device as a function of distance from both the prior art CDMA base station of FIG. 1 as well as the base station in accordance with the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention generally is directed to improvements in the performance of a wireless communication system having elements in RF communication in accordance with a code-based modulation scheme such as CDMA. These improvements are effected by the incorporation of a highly selective filter in a communication station, such as a base station or any other transceiver element designed for RF communication with one or more communication devices (*e.g.*, a mobile, wireless phone). More particularly, these improvements may be obtained in connection with an existing communication station by replacing a filter previously installed and operating therein with a filter having a higher selectivity as set forth hereinbelow.

With reference to FIG. 2, the present invention may be practiced in connection with a wireless communication system generally referred to at 50 having a communication station 52, which may constitute a centralized base station (hereinafter "base station 52") for a cell having one or more generic communication devices 53 located therein. The base station 52 has one or more antennae 54 that may or may not be omni-directional as is known to those skilled in the art. Accordingly, the cell covered by the communication station 52 may, in fact, be divided into a plurality of sectors. For simplicity, the present invention will be set forth in a single cell or sector environment with the understanding that certain components, aspects, or

elements described hereinbelow may need to be replicated, combined or otherwise modified for operation in a multiple sector environment.

Via the antenna 54, the base station 52 receives one or more RF communication signals via respective uplink paths 56A-56C and transmits one or more RF communication signals via respective downlink paths 58A-58C. As used herein, references to an "uplink signal" and a "downlink signal" shall be broadly understood to include any aspect of these RF communication signals. It should be noted that the downlink signals 58A-58C may, in fact, only constitute a single downlink signal for the base station.

The communication system 50 may include any type of communication device capable of RF communication with the base station 52 regardless of the character of the information transmitted via the uplink or downlink signals. For example, the communication system 50 has a mobile wireless phone 60 for the transmission of voice and/or data information, and a fixed and/or mobile computer terminal generally referred to at 62 for the transmission of voice or data information. Similarly, the communication system may include other types of wireless RF communication with fixed devices associated with a business 64 or other residence 66.

In order to establish such RF communication with the communication devices 53 and 66, the base station 52 must have sufficient capacity, which is determined by a host of factors, not the least of which is the throughput of the CDMA processing circuitry responsible for modulating and demodulating the downlink and uplink signals, respectively. Accordingly, the capacity of the base station 52 may also be thought of as composed of an uplink capacity associated with the capability of the base station 52 to process a number of uplink signals, as well as a downlink capacity associated with the capability of the base station 52 to process a number of

downlink signals. The overall capacity of the base station 52, as well as the specific downlink and uplink capacities, may be defined in general terms as the maximum data throughput for the path in question or, more specifically, as the maximum number of users, maximum aggregate bit rate, or some combination thereof.

The base station 52 is shown in greater detail in FIG. 3. As is well known to those skilled in the art, the components of the base station 52 (or any other centrally located transceiver for RF communication over a cell or a plurality of sectors) may be generally separated into those disposed along a transmit path and those disposed along one or more receive paths. The transmit path may terminate with a primary antenna (or antennae) 70, while the receive paths originate with either the primary antenna 70 (in a duplexed configuration as shown) or a diversity receive antenna (or antennae) 72. Coaxial or other cabling of a proper impedance couples the primary and diversity receive antennae 70 and 72 to a duplexer 74 and diversity receive filter 76, respectively. The RF signals handled by these components will be further described hereinbelow with regard to the remaining elements of the receive and transmit paths.

In accordance with one aspect of the present invention, uplink signals collected by the primary and diversity receive antennae 70 and 72 are provided to a highly selective filter 77 (FIG. 4) in the duplexer 74 and the diversity receive filter 76, which also constitutes a highly selective filter. Each highly selective filter 76, 77 is designed to select a desired frequency band of the RF communication signal collected by the antennae 70 and 72 and provided to an input terminal 78 (FIG. 4) or 80, respectively, to provide a filtered, passband response at an output terminal 82 (FIG. 4) or 84, respectively. The output terminals 82, 84 are, in turn, coupled to a pair of

low-noise amplifiers 86, 88 that amplify the filtered output of the filters 76, 77 without introducing any significant losses.

Each highly selective filter 76, 77 is preferably an HTS filter having multiple resonant cavities that utilize superconducting materials to provide excellent rejection while maintaining an extremely low insertion loss. More particularly, such HTS filters may include one or more components having a thick film of a superconducting material. Suitable HTS filters are available from Illinois Superconductor Corporation (Mt. Prospect, Illinois) for a number of cellular and PCS bands and may be obtained in combination with the low-noise amplifiers in an integrated device marketed under the trademarks SpectrumMaster® and RangeMaster®.

The HTS filters 76, 77 need not include thick-film cavity resonators, but rather may be based on a thin-film superconducting filter. Whether based on cavity resonators or thin-film technology, an additional HTS filter may be coupled to the LNA 14 such that the RF receiver is configured in a cascaded filter-LNA-filter configuration as disclosed in co-pending and commonly assigned U.S. Patent Application Serial No. 09/130,274, the disclosure of which is hereby incorporated by reference. Further, any of the aforementioned HTS filters may also constitute a dual-mode, all-temperature filter as disclosed in co-pending and commonly assigned U.S. Patent Application Serial No. 09/158,631, the disclosure of which is also hereby incorporated by reference. Such dual mode filters provide for continued operation during power failures that result in operating temperatures exceeding the critical temperature of the superconducting material.

Other types of highly selective filters may be utilized in lieu of the HTS filter to provide high rejection with low insertion loss. For example, those skilled in the art are readily aware of non-superconducting filters that provide improved responses when operating in a cryogenic environment, as

well as filters containing components made of certain non-superconducting ceramics that have low noise floors. Regardless of the component materials of the filter, a highly selective filter, as used herein, preferably constitutes any ten or more pole filter for a bandwidth of about 1% or more (typically for full or whole band systems), or any filter having five or more poles for a bandwidth of about 0.3% or less (typically for channel-specific systems). More preferably, the filter has twelve or more poles for a bandwidth of about 1% or more, while the filter has six or more poles for a bandwidth of about 0.3% or less. Most preferably, the filter has 16 or more poles for a bandwidth of about 1% or more, while the filter has eight or more poles for a bandwidth of about 0.3% or less.

The HTS or other highly selective filter also preferably has an additive noise contribution of about 1dB or less, more preferably about 0.7 dB or less, and most preferably about 0.5 dB or less. It shall be noted that the foregoing noise floor figures are, of course, temperature-dependent and, therefore, may need to be adjusted therefor.

Each HTS filter 76, 77 is coupled to the LNAs 86, 88 via a respective 50 Ohm coaxial cable or other suitable transmission line known to those skilled in the art. To avoid reflection, and, therefore, signal loss, the transmission line should be impedance-matched to the HTS filters 76, 77 and LNAs 86, 88. Each LNA 86, 88 outputs a filtered, amplified RF signal having a fixed amount of gain over a frequency range set to correspond with the passband of the HTS filters 76, 77. For example, the LNAs 86, 88 may provide about 25 dB of gain over the frequency range 1850 to 1910 MHz with a maximum noise figure of about 1.2 dB (at room temperature). In accordance with one embodiment of the present invention, each LNA 86, 88 is a GaAs-based amplifier to allow for operation at cryogenic temperatures. Such an LNA is available from JCA Technology (Camarillo, California) as

product number JC12-2342D. Alternatively, the LNA 86, 88 provides similar gain levels over a lower frequency range (824 to 849 MHz). Such an LNA is available from JCA Technology as product number JCA01-3149.

In accordance with an alternative embodiment of the present invention, the LNAs 86, 88 are any one of a number of commercially available, non-cryogenic low-noise amplifiers.

FIG. 4 shows the above-described highly selective filters 76, 77 and LNAs 86, 88 as disposed within a single cryostat 90. A suitable cryostat is available via Illinois Superconductor Corporation in connection with the above-noted integrated device. Taken together with the primary and diversity receive antennae 70, 72 and any intervening cables, these elements of the base station 52 may be considered a "front end" or part of an RF module (generally referred to at 91) and responsible for reception of the RF uplink signals. Also shown in FIG. 4 are the remaining components of the RF module 91 (on the transmit path) of the base station 52, namely a transmit filter 92 and a linear power amplifier (LPA) 94. In operation, the LPA 94 amplifies an RF signal generated by the base station 52 for transmission on the downlink via the primary antenna 70. The transmit filter 92 is disposed within the duplexer 74 to couple the LPA 94 to the primary antenna 70 and attenuate any frequency components that may interfere with reception of the uplink signals. The transmit filter 92 may be a conventional filter or, alternatively, include components having superconducting materials. A duplexer having both the transmit filter 92 as well as the filters 76, 77 disposed within a cryostat is available from Illinois Superconductor Corporation. While any conventional bandpass filter typically used in the transmit path may be generally utilized (*e.g.*, the transmit filter that is provided with a Motorola SC 614T Base Transceiver Subsystem), superconducting transmit filters may provide needed rejection

when the downlink frequency band is particularly close to the uplink frequency band.

With reference again to FIG. 3, the RF module 91 (FIG. 4) generally interfaces with a data processing module 100 via a transmit input terminal 102, a primary receive output terminal 104, and a diversity receive input terminal 106. The data processing module 100 should be generally understood to include components of the base station 52 that do not only operate at RF frequencies, but rather also process the signals along the uplink and downlink paths at intermediate frequencies (IF), at the baseband frequency, or in digital form. The data processing module 100 accordingly includes, but is not limited to the hardware and software associated with digital signal processing algorithms such as coding/decoding and error correction, as well as circuitry directed to the interface with the RF module 91, such as modulation and equalization.

With regard to the primary and diversity receive paths, the filtered and amplified RF signals provided by the LNAs 86, 88 are downconverted to an intermediate frequency or directly to the baseband frequency using respective downconverter circuitry (*i.e.*, a mixer) 102, 104 or other components well known to those skilled in the art. Filtering and other signal processing in the IF band may then occur to the extent necessary to prepare for demodulation of the received communication signals by one or more demodulators 106 responsive to signals modulated in accordance with the code-based modulation scheme. More particularly, the demodulator 106 is preferably a CDMA demodulator in the sense that the demodulator 106 filters the spread spectrum of the baseband signal to extract the separate channels coded therein. As such, the demodulator 106 corresponds in a functional sense with aspects of both the TRX module and the wideband interface of the above-noted Motorola SC 614T BTS, and need not be

implemented in any particular configuration. In addition to the processing in accordance with the CDMA or other codes, the demodulator 106 may also process the signals to remove QPSK or other modulation schemes utilized to aid in transmission. After demodulation and CDMA processing, the resulting bitstreams are provided to a central controller 108 for the base station 52 for further processing, such as a strength comparison between the primary and diversity receive signals, and further transmission to another communication station (not shown) in the communication network.

As is well known to those skilled in the art, the central controller 108 includes hardware, software, firmware, or any combination thereof, to execute algorithms that determine the content (*i.e.*, instructions) contained in power control messaging for the plurality of communication devices. The power control messaging, in turn, control the power level at which the communication device transmits an uplink signal.

In the transmit path, a downlink signal is generated or otherwise provided in digital form by the central controller 108 for processing by a modulator 110. The circuitry associated with the modulator 110 not only prepares the analog baseband signal in accordance with the code-based modulation scheme (*e.g.*, CDMA), but further converts the baseband signal into a QPSK or other type of signal that may be suitable for transmission. The QPSK or other modulated signal is provided to upconverter or mixer circuitry 112 to develop an RF signal for transmission via those components of the RF module 91 in the transmit path.

Operation of the above-described code-based communication system in accordance with the present invention has shown improved and unexpected performance results over systems currently in use. In accordance with one aspect of the present invention, improved performance results were shown by first establishing RF communication between a

plurality of mobile wireless units and a communication station corresponding with or similar to the above-noted Motorola base station, and then modifying the communication station by replacing the RF selection filters in the primary and diversity receive paths with highly selective filters as set forth hereinabove. The screen captures and graphs of FIGS. 5A-B and 6-8 provide data representative of the improved RF communication that was then established between the communication devices and the modified communication station.

FIGS. 5A and 5B show the results of a comparison of the capacity of a test sector of a base station having non-highly selective filters in the receive paths coupled to non-cryogenic LNAs with the base station modified from its original configuration to include a RangeMaster front end in the receive paths instead of the non-highly selective filters and non-cryogenic LNAs. The transmit filter in the transmit path was also replaced to ensure that the impedances in the duplexer were consistent. However, it should be noted that the replacement filter was still a non-highly selective filter and with, in fact, a slightly lower selectivity than the replaced filter. Thus, it is submitted that the only substantive modification to the base station components in accordance with the present invention occurred in connection with the receive path, although practice of the present invention is not limited to such a modified configuration.

The other sectors of the base station were artificially loaded to ensure that traffic would be routed to the test sector during the comparison. Monitoring equipment was coupled to the base station components appropriately to measure channel energy for the downlink signal. Because voice activity and other data transmitted via the uplink would affect the capacity comparison, the comparison data was taken with no activity on the uplink to ensure that the tests were downlink-limited. Therefore, the

capacity being compared is actually the downlink capacity of the base station.

For each base station configuration, a number of wireless communication devices were utilized to determine the maximum number of calls that could be assigned. The devices were located near the edge of the cell and held stationary. As shown in FIG. 5A, the conventional base station allowed nine calls to be assigned to channels (other than the non-traffic channels, such as the pilot, synchronization, and paging channels) before the base station would begin to drop calls. Each call has a channel energy that appears as a bar extending above the noise floor. Upon replacing the filters and LNAs as described hereinabove and establishing RF communication using the modified base station, the downlink capacity increased to allow the assignment of an additional five calls, as shown in FIG. 5B (for a total of fourteen channels minus the three control or non-traffic channels).

Also shown in the screen captures of FIGS. 5A and 5B is a depiction of the total power associated with the downlink signal. The total transmit power of the conventional base station was 40.88 dB above 1 mW (dBm), while the total transmit power of the modified base station was only 38.55 dBm. Thus, the base station having the highly selective filter not only has the increased capacity to handle more calls, but also does so with a reduction in total power, thereby suggesting that the power control algorithms executed by the central controller 108 are more efficiently allocating the power amongst the traffic and control channels.

The next series of comparison tests were directed to gathering data with a mobile test device as it was moved relative to the base station. The mobile test device was capable of monitoring aspects of both the uplink and the downlink signals, and, in particular, the mobile transmit power (MTX)

(FIG. 6), the received signal strength indicator (RSSI) (FIG. 7), and the signal bit energy to noise floor ratio for the pilot channel (E_c/I_o) (FIG. 8). In each of the graphs of FIGS. 6-8, the data gathered by the mobile test device is plotted as a function of latitude position (as measured using a GPS device), which corresponds with distance from the base station. Increasing latitude corresponds with increased distance between the mobile and the base station.

The graphs of FIGS. 6-8 set forth the collected data for both the conventional and modified base stations as actually measured and according to linear regression analysis. The results of the linear regression analysis will be identified and further described in connection with each particular graph.

The graph of FIG. 6 includes a linear regression line 200 representing the average mobile transmit power during operation of the conventional base station and a linear regression line 202 representing the average mobile transmit power during operation of the modified base station. During each stage of the comparison test, seven devices were allocated to channels other than the channel allocated to the test unit. By comparing the lines 200 and 202, it is shown that the mobile device was instructed to transmit (and capable of transmitting) at a lower power for all distance points monitored.

The graph of FIG. 7 compares the RSSI levels for the test unit as it moved along the same path traversed in FIG. 6. Generally, the RSSI measurement is reflective of how well a communication device is receiving the downlink signal. A linear regression line 204 shows that the signal strength decreased considerably as the test unit was moved away from the conventional base station, while a line 206 shows that the signal strength remained relatively constant despite the increases in transmission distance.

The lack of any appreciable decrease in signal strength is remarkable considering the lack of any substantive modifications to the transmit path and may be indicative of an increase in efficiency and consistency in the ability of the central controller to allocate power.

The graph of FIG. 8 shows the pilot channel bit energy ratio as received by the test unit as it moved along the same path traversed in FIGS. 6 and 7. As will be appreciated by those skilled in the art, generally speaking, if the signal bit energy ratio falls below -14, a communication device will lose the pilot channel (in the noise floor) and be forced to drop the call. Nevertheless, it is desirable to devote a minimum amount of power to the pilot channel in the interest of allocating maximum power to the traffic or voice channels. A line 208 corresponds with the signal bit energy ratio for operation with the conventional base station, while a line 210 shows a consistently lower signal bit energy for operation with the modified base station. Based on the foregoing, it appears that less power is being allocated to the pilot channel due to a modification in the receive path of the base station. This is consistent with the lower total transmit power used to support a higher number of calls, as depicted in FIG. 5B.

The foregoing test comparisons demonstrate that the following improvements in base station performance may be realized in communication stations practicing the present invention:

(1) an increased capacity on the uplink path, in the sense that the maximum number of simultaneous users on the uplink path will increase or, alternatively, that the aggregate bit rate for a channel (or channels) will increase;

(2) an increased capacity on the downlink path, in the sense that the maximum number of simultaneous users on the

downlink path will increase or, alternatively, that the aggregate bit rate for a channel (or channels) will increase.

(3) a reduction in the average transmit power of the communication devices transmitting uplink signals;

(4) a reduction in the average power of the pilot channel of the downlink signal;

(5) increase accuracy of the power control algorithms that determine the transmit power of the mobile units for more consistent and efficient allocation of power; and

(6) a reduced size of the guardbands between adjacent CDMA channels based on the higher selectivity provided by the HTS and other highly selective filters.

The CDMA system described hereinabove may be one of several different code-based modulation schemes or wireless air interfaces. For example, the CDMA system may follow the IS-95 CDMA air interface standard or, alternatively, the cdma2000 standard, the W-CDMA standard, or any other code-based modulation scheme. As a result, it shall be understood that practice of the present invention is not limited to any particular frequency band or code structure set.

It shall be further understood that the present invention is not limited to any particular physical configuration of the components in the RF module, inasmuch as the highly selective filters and LNAs may or may not be integrated into a single, stand-alone unit. Furthermore, the present invention is not limited to an RF module having either a simplex or duplex configuration, nor is it limited to a base station having a certain number of sectors.

When the receive or transmit paths include HTS filters, the RF module may include a bypass mechanism to determine when the HTS filters should or should not process an incoming signal. The election to bypass an HTS filter may be addressed by a controller integrated into the stand-alone unit, as described in commonly assigned and co-pending application

Although the RF receiver 10 is particularly well suited for use with wireless telecommunication systems and will be discussed in that context herein, persons of ordinary skill in the art will readily appreciate that the teachings of the invention are in no way limited to such an environment of use. On the contrary, receivers constructed pursuant to the teachings of the invention may be employed in any application which would benefit from the high performance filtering and variable amplification that it provides without departing from the scope or spirit of the invention. In that spirit, as used herein, "communication station" should be understood to include any type of communication terminal in a system in which RF signals are transmitted and/or received and, therefore, should include, but not be limited to, a cellular telephone base station.

The foregoing detailed description has been given for clearness of understanding only, and no unnecessary limitations should be understood therefrom, as modifications would be obvious to those skilled in the art.

Claims:

1. A communication station having an antenna for receiving a communication signal modulated in accordance with a code-based modulation scheme, comprising:

a highly selective filter having an input and an output wherein the input is coupled to the antenna;

a low-noise amplifier coupled to the output of the highly selective filter; and

a demodulator coupled to the low noise amplifier and responsive to signals modulated in accordance with the code-based modulation scheme.

2. The communication station of claim 1, wherein the code-based modulation scheme is CDMA.

3. The communication station of claim 2, wherein the highly selective filter comprises a high-temperature superconducting component.

4. The communication station of claim 3, wherein the low-noise amplifier is a non-cryogenic amplifier.

5. The communication station of claim 3, further comprising a cryostat in which the low-noise amplifier is disposed.

6. The communication station of claim 3, further comprising a transmission filter coupled to the antenna.

7. The communication station of claim 6, wherein the transmission filter is a non-superconducting filter.

8. The communication station of claim 1, wherein --
the demodulator is part of a data processing module; and
the low-noise amplifier is directly connected to the data processing module.

9. The communication station of claim 1, wherein the highly selective filter has an additive noise contribution of no more than about 1 dB.

10. The communication station of claim 1, wherein the highly selective filter includes no less than ten poles for a bandwidth of no less than about 1%.

11. The communication station of claim 1, wherein the highly selective filter includes no less than five poles for a bandwidth of no greater than about 0.3%.

12. The communication station of claim 1, wherein the code-based modulation scheme is W-CDMA.

13. The communication station of claim 1 in combination with a communication device in RF communication therewith via an uplink signal transmitted from the communication device and a downlink signal transmitted to the communication device wherein the downlink signal comprises power control messaging determinative of a power level of the uplink signal.

14. The combination of claim 13, wherein reception of the uplink signal via the highly selective filter reduces the power control messaging.

15. The combination of claim 13, wherein reception of the uplink signal via the highly selective filter reduces the power level of the communication device.

16. The combination of claim 13, in further combination with an additional communication device in RF communication with the communication station utilizing channel capacity made available by the reduced power control messaging.

17. The combination of claim 16, wherein reception of the uplink signal via the highly selective filter increases capacity for receiving a further uplink signal associated with the additional communication device.

18. A communication station having an antenna for receiving a communication signal modulated in accordance with a code-based modulation scheme, comprising:

a filter having an input and an output wherein --

the input is coupled to the antenna, and

the filter comprises a high-temperature superconducting component;

a low-noise amplifier coupled to the output of the highly selective filter; and

a demodulator coupled to the low-noise amplifier and responsive to signals modulated in accordance with the code-based modulation scheme.

19. The communication station of claim 18, wherein the code-based modulation scheme is CDMA.

20. The communication station of claim 19, wherein the low-noise amplifier is a non-cryogenic amplifier.

21. The communication station of claim 19, further comprising a cryostat in which the low-noise amplifier is disposed.

22. The communication station of claim 19, further comprising a transmission filter coupled to the antenna.

23. The communication station of claim 22, wherein the transmission filter is a non-superconducting filter.

24. The communication station of claim 18, wherein --

the demodulator is part of a data processing module; and

the low-noise amplifier is directly connected to the data processing module.

25. The communication station of claim 18 in combination with a communication device in RF communication therewith via an uplink signal transmitted from the communication device and a downlink signal transmitted to the communication device wherein the downlink signal comprises power control messaging determinative of a power level of the uplink signal.

26. The combination of claim 25, wherein reception of the uplink signal via the highly selective filter reduces the power control messaging.

27. The combination of claim 25, wherein reception of the uplink signal via the highly selective filter reduces the power level of the communication device.

28. The combination of claim 25, in further combination with an additional communication device in RF communication with the communication station utilizing channel capacity made available by the reduced power control messaging.

29. The combination of claim 28, wherein reception of the uplink signal via the highly selective filter increases capacity for receiving a further uplink signal associated with the additional communication device.

30. A communication station having an antenna for receiving a communication signal modulated in accordance with a code-based modulation scheme, comprising:

a highly selective filter having an input and an output wherein the input is coupled to the antenna;

a low-noise amplifier coupled to the output of the highly selective filter to develop an amplified and filtered communication signal; and

a demodulator coupled to the low noise amplifier and responsive to signals modulated in accordance with the code-based modulation scheme wherein the amplified and filtered communication signal is provided to the demodulator without further significant RF selection filtering.

31. The communication station of claim 30, wherein the code-based modulation scheme is CDMA.

32. The communication station of claim 31, wherein the highly selective filter comprises a high-temperature superconducting material.

33. The communication station of claim 32, wherein the low-noise amplifier is a non-cryogenic amplifier.

34. The communication station of claim 32, further comprising a cryostat in which the low-noise amplifier is disposed.

35. The communication station of claim 30, wherein the highly selective filter has an additive noise contribution of about no more than 1 dB.

36. The communication station of claim 30, further comprising a transmission filter coupled to the antenna.

37. The communication station of claim 36, wherein the transmission filter is a non-superconducting filter.

38. The communication station of claim 30, wherein --

the demodulator is part of a data processing module; and

the low-noise amplifier is directly connected to the data processing module.

39. The communication station of claim 30 in combination with a communication device in RF communication therewith via an uplink signal transmitted from the communication device and a downlink signal transmitted to the communication device wherein the downlink signal comprises power control messaging determinative of a power level of the uplink signal.

40. A communication system comprising:

a communication device; and

a base station in RF communication with the communication device in accordance with a code-based modulation scheme and including a highly selective filter in a receive path.

41. The communication system of claim 40, wherein the highly selective filter comprises a high-temperature superconducting component.

42. The communication system of claim 41, wherein the base station further includes a non-cryogenic low-noise amplifier.

43. The communication system of claim 41, wherein the base station further includes a low-noise amplifier and a cryostat in which the low-noise amplifier is disposed.

44. The communication system of claim 43, wherein —

the base station further includes a transmission filter and an antenna; and

the highly selective filter in the receive path and the transmission filter are coupled to the antenna.

45. The communication system of claim 44, wherein the transmission filter is a non-superconducting filter.

46. The communication system of claim 44, wherein the highly selective filter in the receive path is directly connected to the antenna.

47. The communication system of claim 41, wherein –

the RF communication between the base station and the communication device includes a downlink signal transmitted by the base station and an uplink signal received by the base station; and

the downlink signal comprises a pilot channel for transmitting power control messaging to control a power level of the communication device.

48. The communication system of claim 47, wherein reception of the uplink signal via the highly selective filter reduces the power control messaging on the pilot channel.

49. The communication system of claim 47, wherein reception of the uplink signal via the highly selective filter reduces the power level of the communication device.

50. The communication system of claim 47, further comprising an additional communication device in RF communication with the communication station utilizing channel capacity made available by the reduced power control messaging.

51. The communication system of claim 47, wherein –

the downlink signal has a signal strength as received at the communication device; and

reception of the uplink signal via the highly selective filter stabilizes the signal strength over a range of RF communication distances.

52. The communication system of claim 41, wherein the base station comprises a demodulator and a low-noise amplifier coupling the demodulator to the highly selective filter.

53. The communication system of claim 52, wherein --

the demodulator is part of a data processing module; and

the low-noise amplifier is directly connected to the data processing module.

54. The communication system of claim 53, wherein the code-based modulation scheme is CDMA.

55. The communication system of claim 51, wherein the highly selective filter has an additive noise contribution of no more than about 1 dB.

56. The communication system of claim 51, wherein the highly selective filter includes no less than ten poles for a bandwidth of no less than about 1%.

57. The communication station of claim 51, wherein the highly selective filter includes no less than five poles for a bandwidth no greater than about 0.3%.

58. The communication system of claim 51, wherein --

the communication device is one of a plurality of communication devices in RF communication with the base station;

the base station includes a transmitter such that the RF communication includes a downlink;

the base station has a downlink capacity for transmitting signals to the plurality of communication devices; and

the highly selective filter in the receive path increases the downlink capacity.

59. The communication system of claim 41, wherein the code-based modulation scheme is W-CDMA.

60. A method of improving performance of a communication station having a receive path, comprising the steps of:

(a) establishing RF communication between a plurality of communication devices and the communication station in accordance with a code-based modulation scheme wherein the receive path comprises a first filter;

(b) modifying the communication station by replacing the first filter with a second, highly selective filter having a selectivity higher than the first filter; and

(c) establishing improved RF communication between the plurality of communication devices and the modified communication station.

61. The method of claim 60, wherein the highly selective filter comprises a high-temperature, superconducting component.

62. The method of claim 61, wherein the code-based modulation scheme is CDMA.

63. The method of claim 62, wherein --

the communication station further includes a transmit path,

the RF communication includes a downlink signal that passes through the transmit path and an uplink signal that passes through the receive path, and

the improved RF communication includes increased capacity for both the uplink signal and the downlink signal.

64. The method of claim 63, wherein the downlink signal comprises a pilot channel for transmitting power control messaging to control a power level of a certain device of the plurality of communication devices.

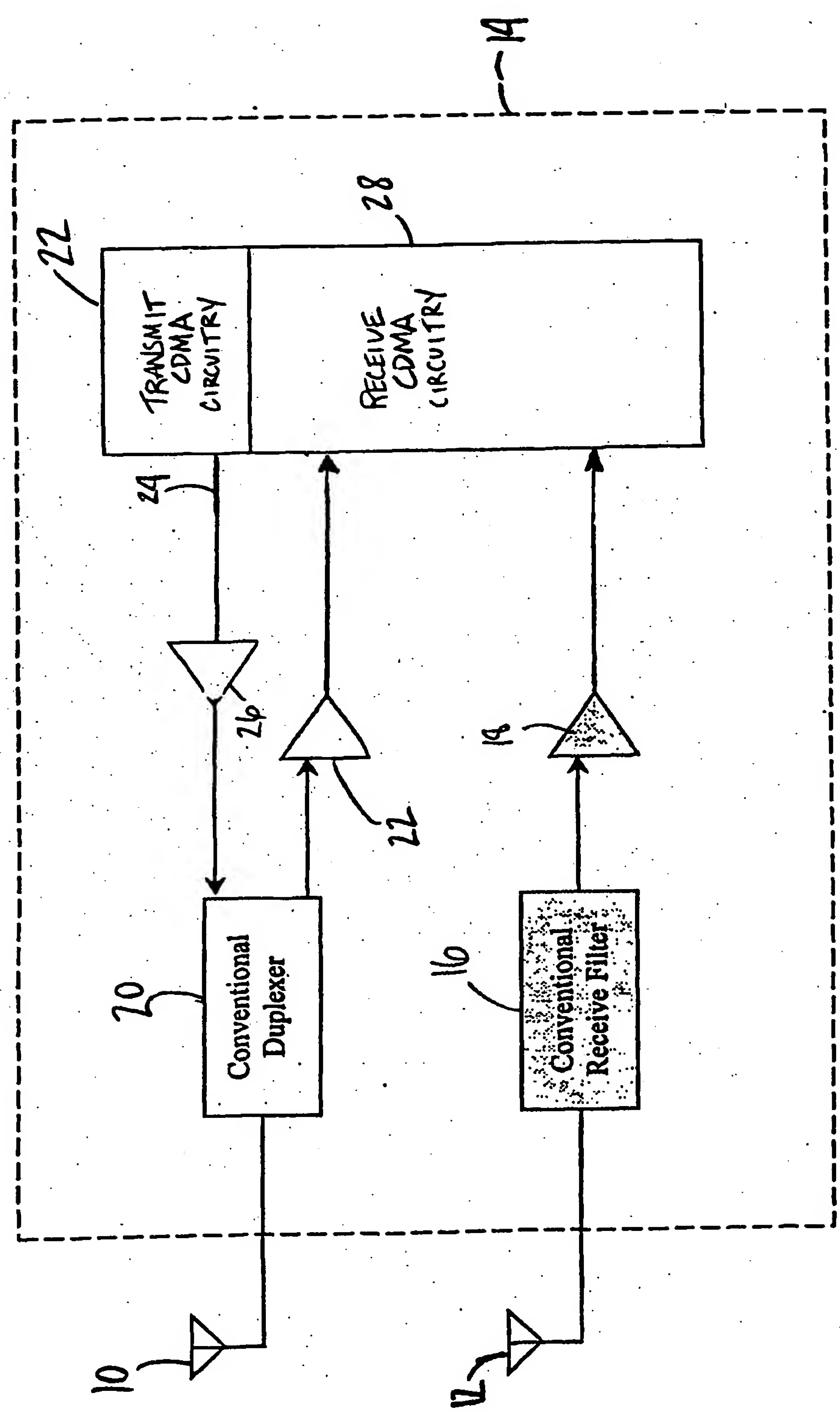
65. The method of claim 64, wherein the improved RF communication includes a reduction in the power control messaging on the pilot channel.

66. The method of claim 64, wherein the improved RF communication includes a reduction in the power level of the certain device of the plurality of communication devices.

67. The method of claim 64, wherein --

the downlink signal has a signal strength as received at the certain device of the plurality of communication devices, and

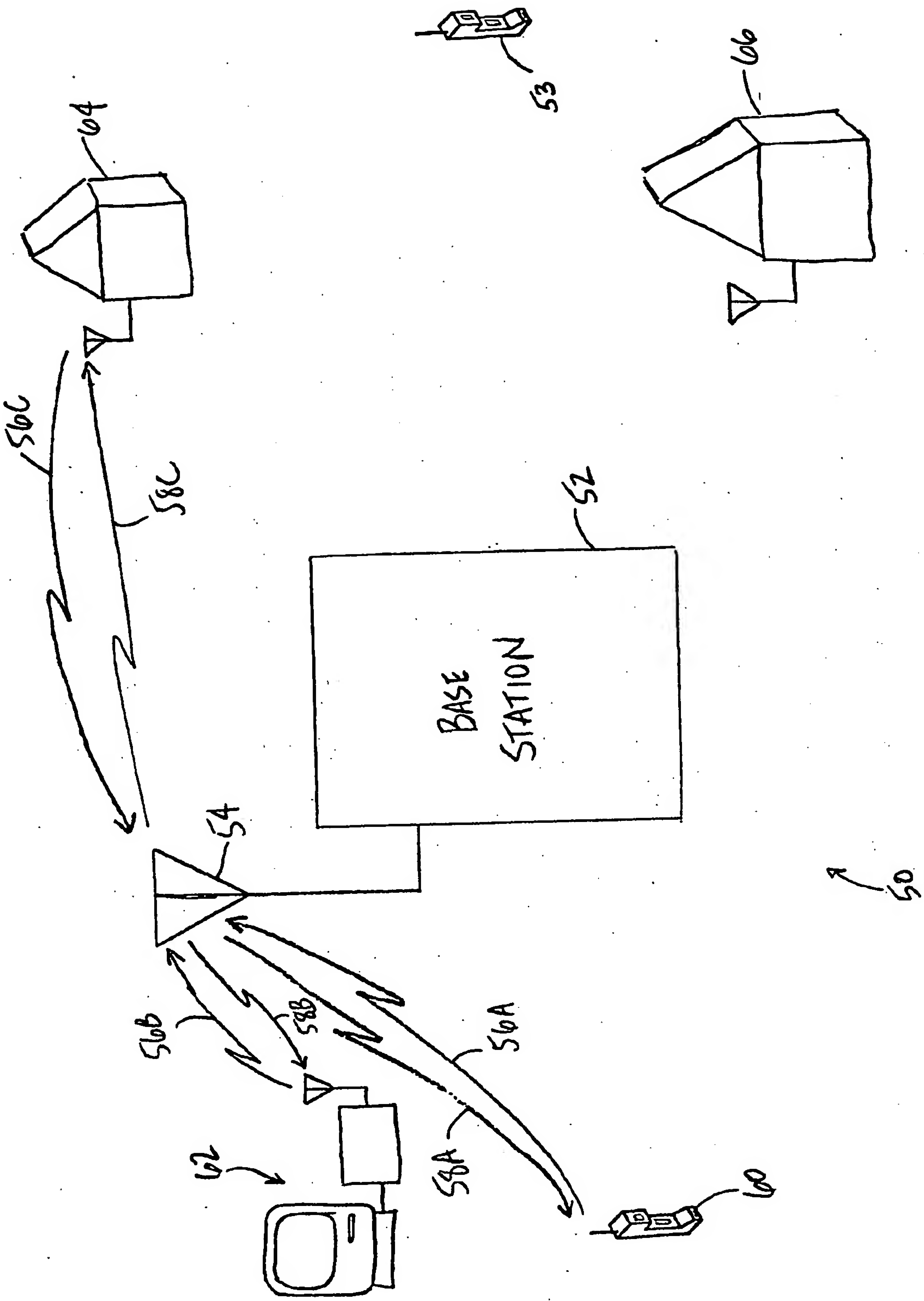
the improved RF communication includes a stabilization of the signal strength over a range of RF communication distances.



PRIOR ART

FIG. 1

FIG. 2



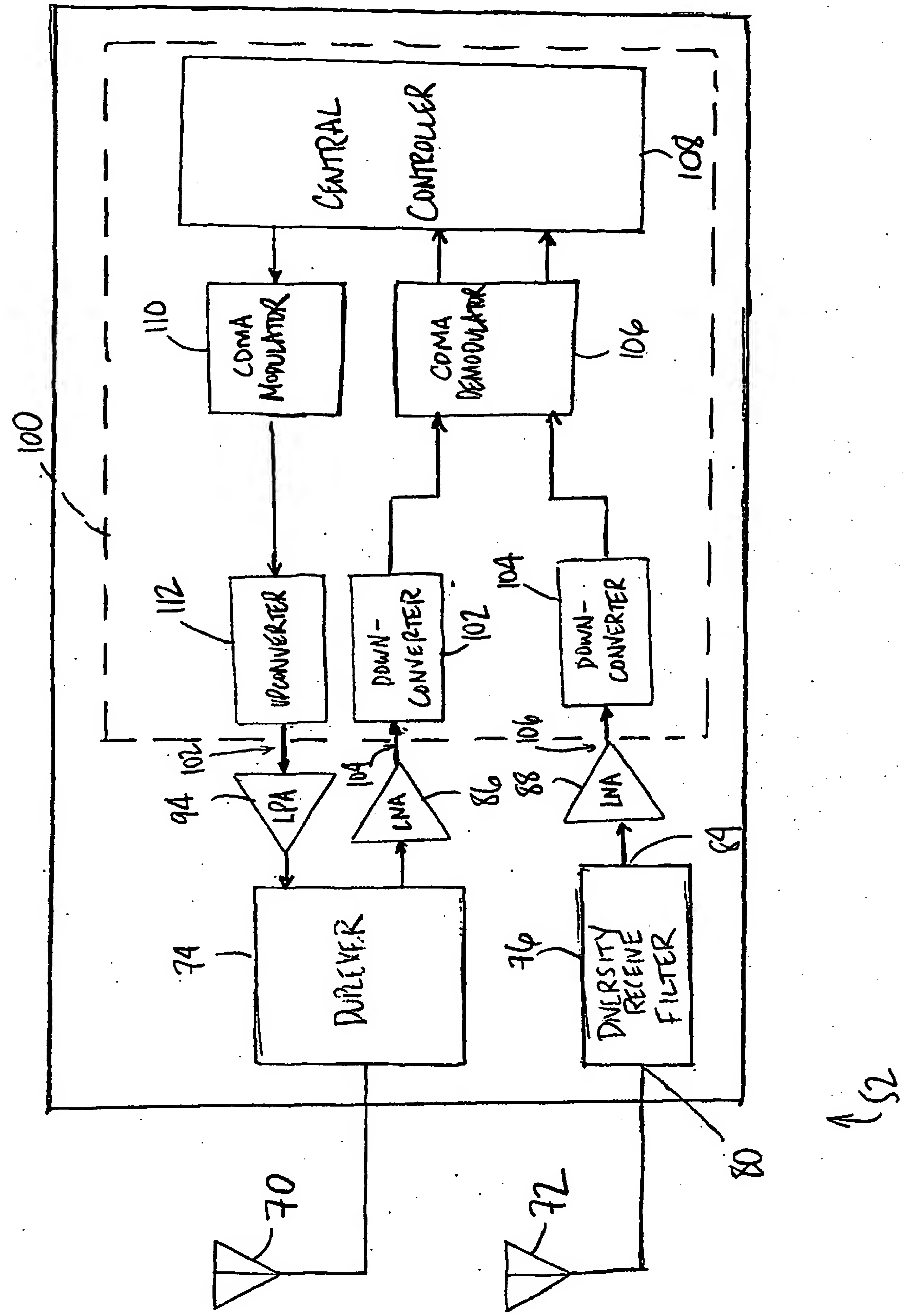

CENTRAL CONTROLLER
108
CDMA MODULATOR
110
CDMA DEMODULATOR
106
100
UPCONVERTER
112
DOWN-CONVERTER
102
DOWN-CONVERTER
104
LPA
94
LNA
86
LNA
88
DUPLEXER
74
DIVERSITY RECEIVE FILTER
76
84
80
70
72
52

FIG. 3

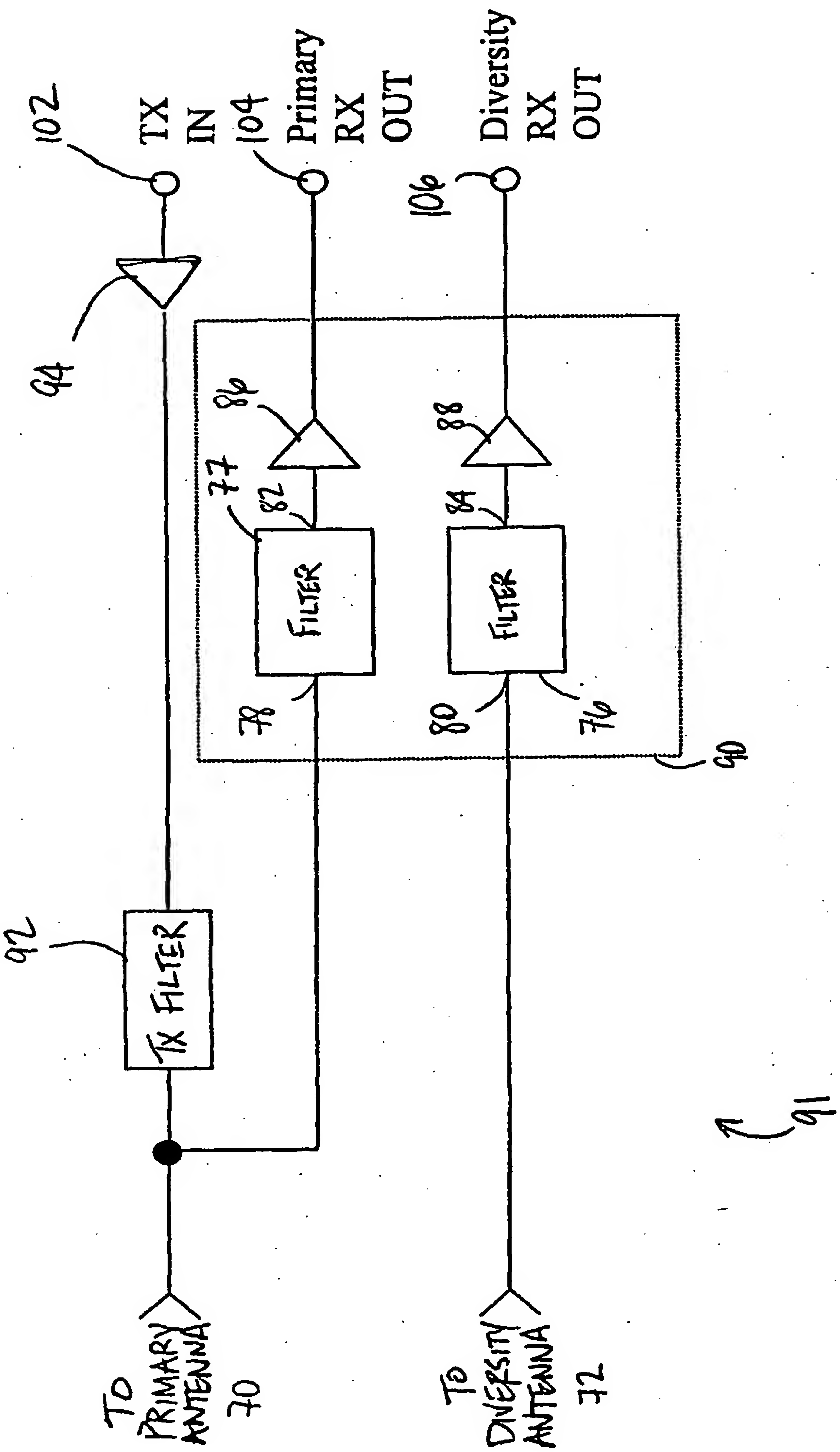
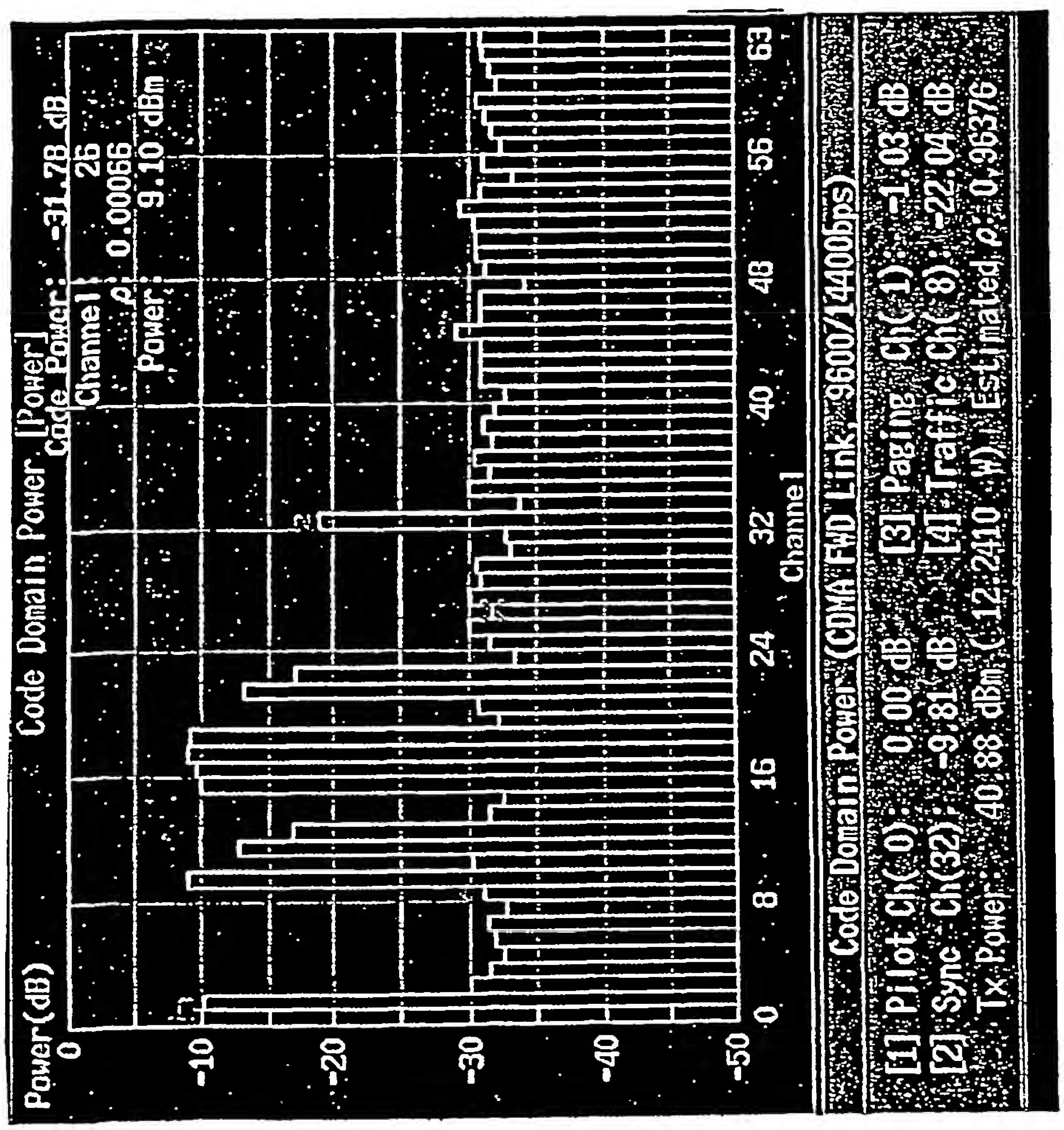

102
TX IN
104
Primary RX OUT
106
Diversity RX OUT
94
86
88
77
82
84
FILTER
FILTER
78
80
76
90
92
TX FILTER
91
TO PRIMARY ANTENNA 70
TO DIVERSITY ANTENNA 72

FIG. 4

PRIOR ART

FIG. 5A



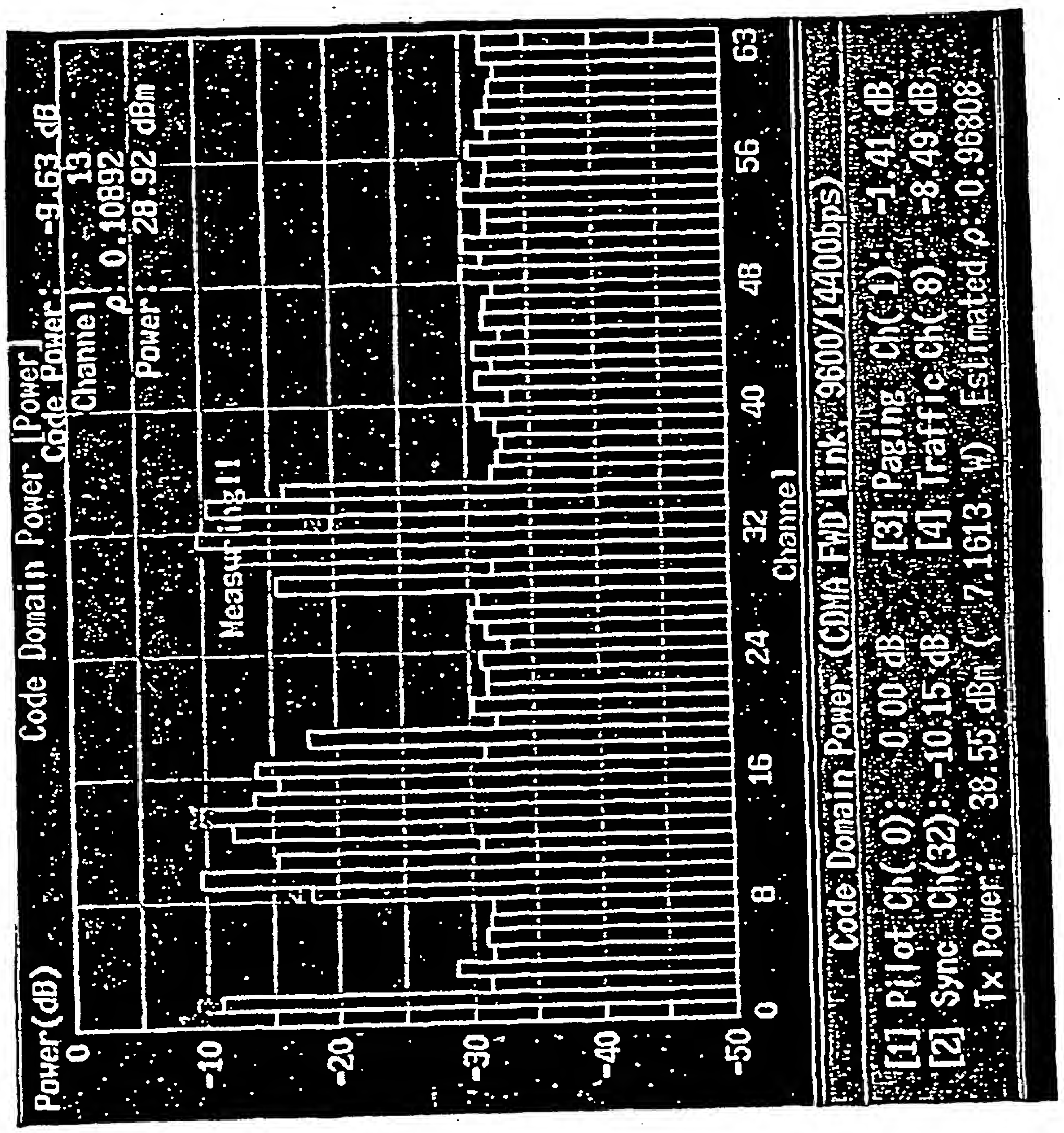
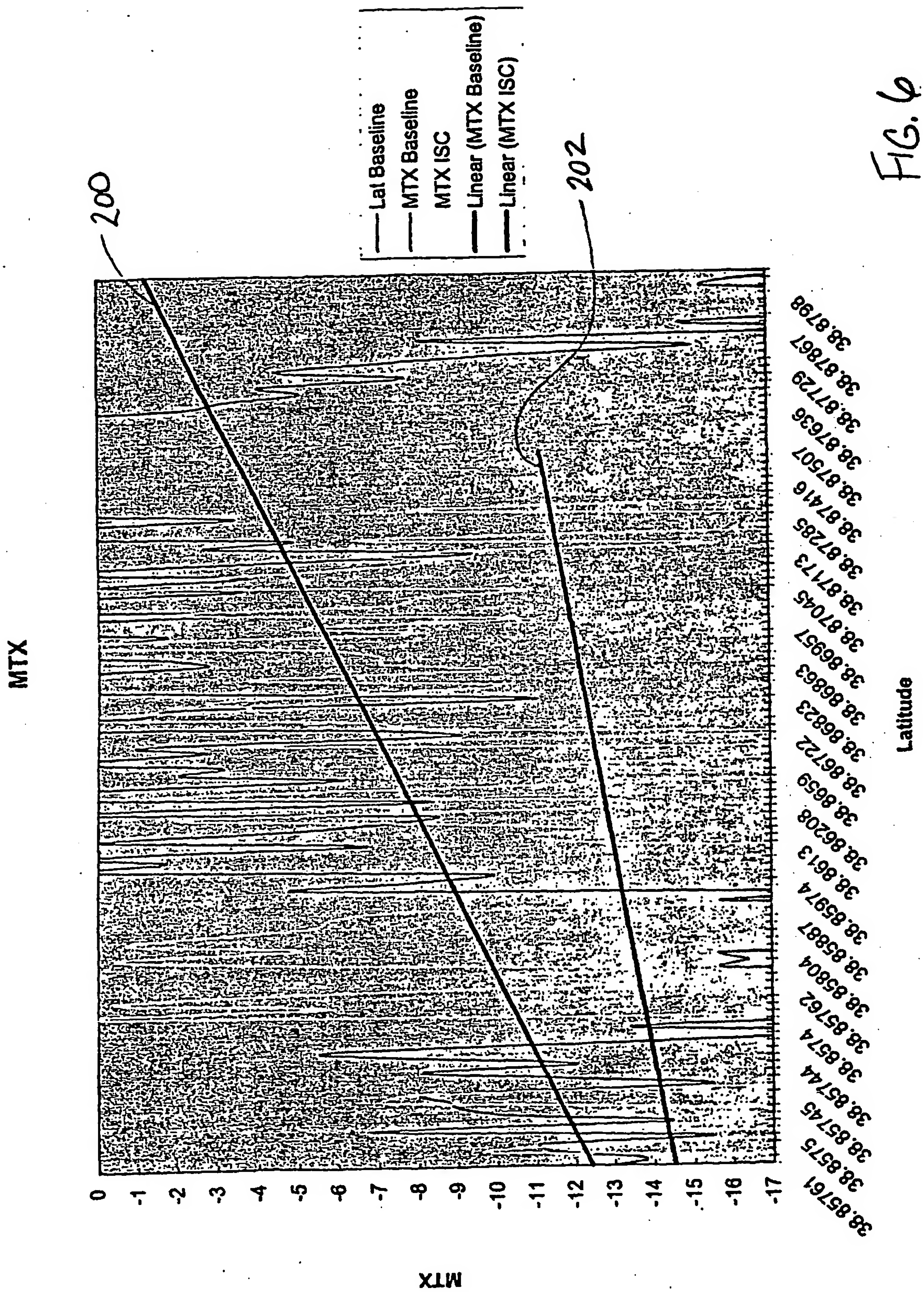

Code Domain Power [Power]
Code Power: -9.63 dB
Channel 13
ρ: 0.10892
Power: 28.92 dBm
Power(dB)
0
-10
-20
-30
-40
-50
Measuring!!
0 8 16 24 32 40 48 56 63
Channel
Code Domain Power (CDMA FWD Link 9600/14400bps)
[1] Pilot Ch(0): 0.00 dB
[3] Paging Ch(1): -1.41 dB
[2] Sync Ch(32): -10.15 dB
[4] Traffic Ch(8): -8.49 dB
Tx Power: 38.55 dBm (7.1613 W)
Estimated ρ: 0.96808

FIG. 5B


MTX
Lat Baseline
MTX Baseline
MTX ISC
Linear (MTX Baseline)
Linear (MTX ISC)
200
202
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
MTX
38.85761
38.8575
38.85745
38.85744
38.8574
38.85762
38.85804
38.85887
38.85974
38.8613
38.86208
38.8659
38.86722
38.86823
38.86863
38.86957
38.87045
38.87173
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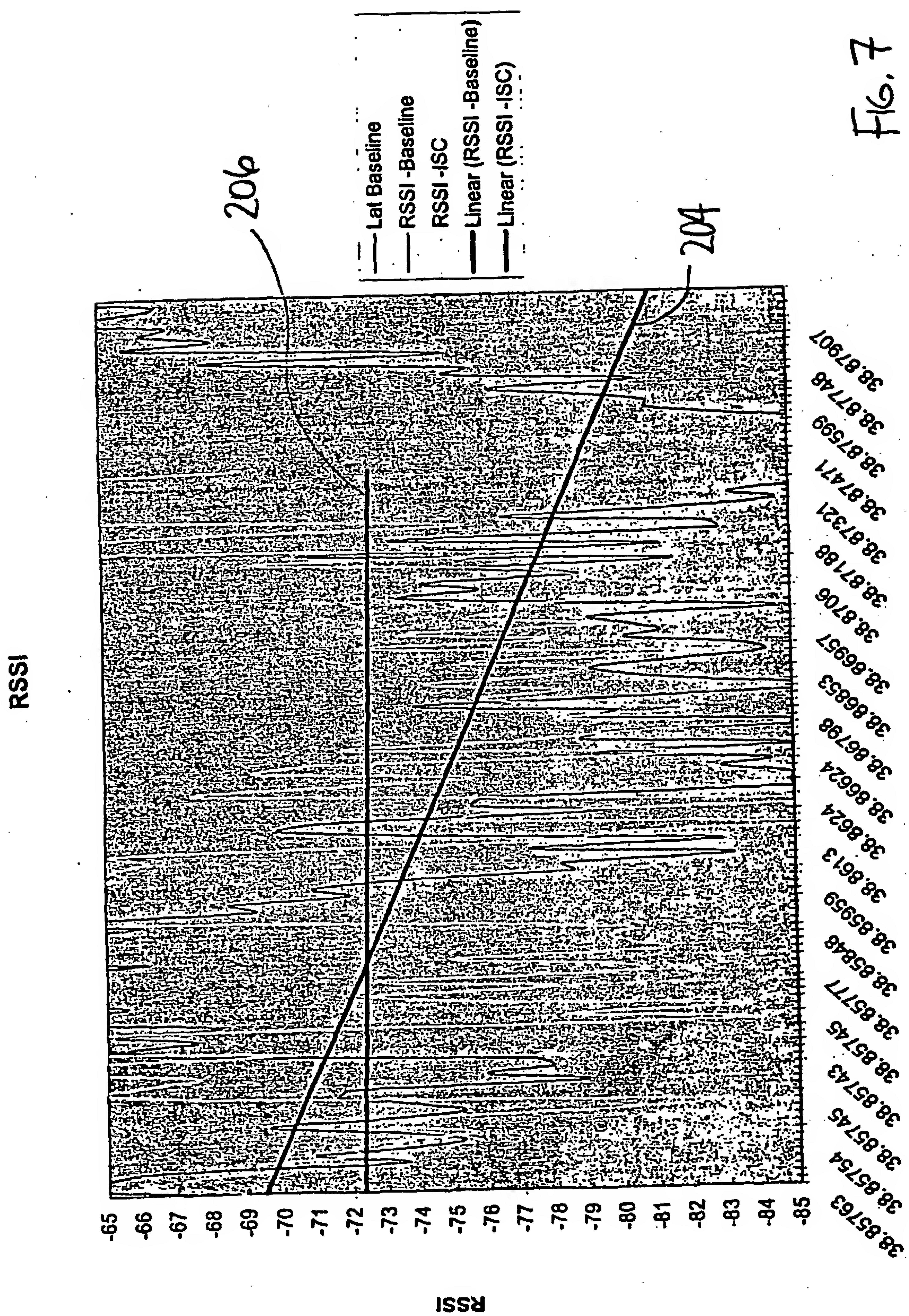
38.87416
38.87507
38.87636
38.87729
38.87867
38.8798
Latitude

FIG. 6


RSSI
Lat Baseline
RSSI -Baseline
RSSI -ISC
Linear (RSSI -Baseline)
Linear (RSSI -ISC)
206
204
-65
-66
-67
-68
-69
-70
-71
-72
-73
-74
-75
-76
-77
-78
-79
-80
-81
-82
-83
-84
-85
38.87907
38.87748
38.87599
38.87471
38.87321
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38.8624
38.8613
38.85959
38.85848
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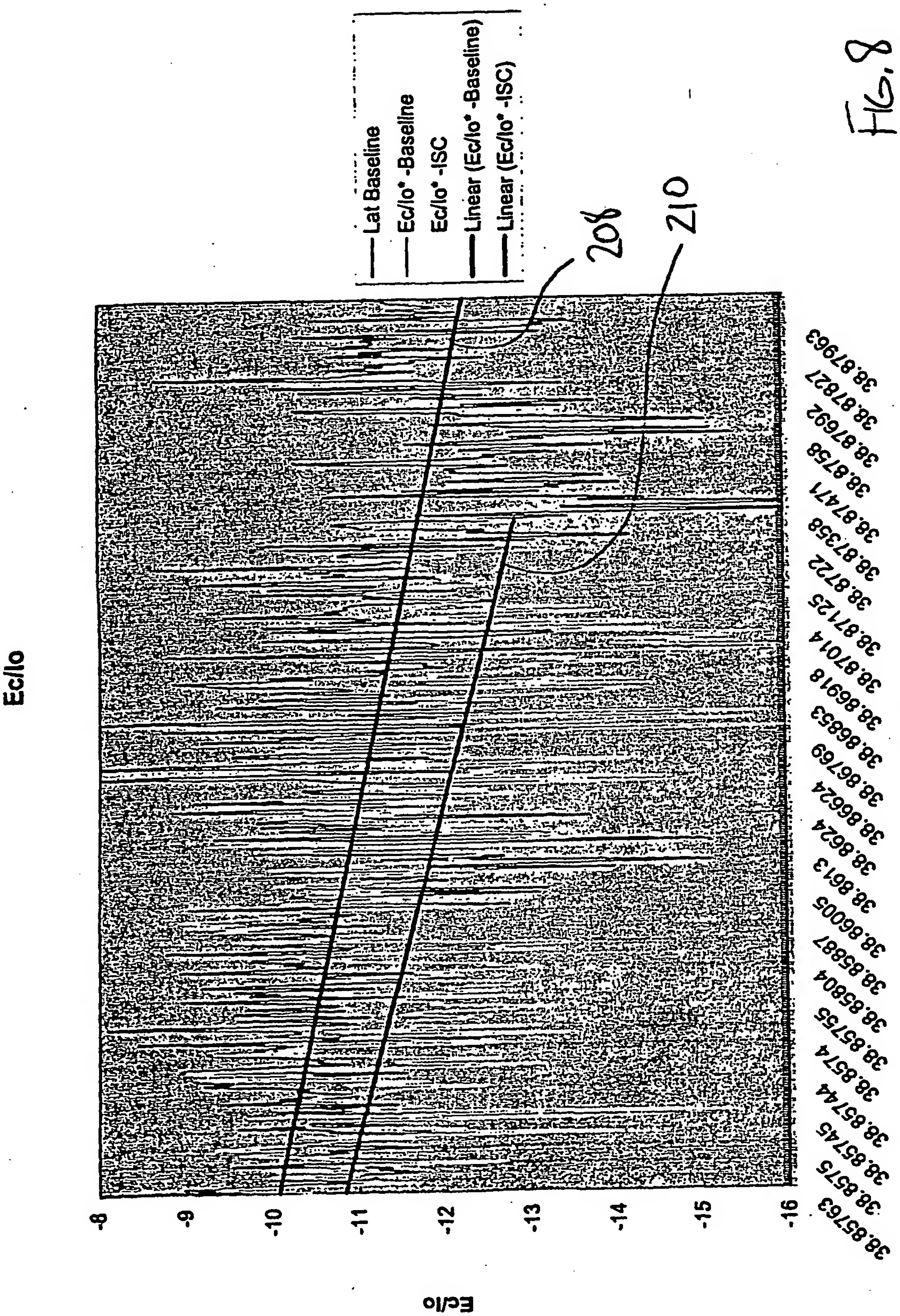
38.85745
38.85743
38.85745
38.85754
38.85763
Latitude
RSSI

FIG. 7


Ec/Io
Lat Baseline
Ec/Io* -Baseline
Ec/Io* -ISC
Linear (Ec/Io* -Baseline)
Linear (Ec/Io* -ISC)
208
210
-8
-9
-10
-11
-12
-13
-14
-15
-16
Ec/Io
38.87963
38.87827
38.87692
38.8758
38.87471
38.87358
38.8722
38.87125
38.87014
38.86918
38.86853
38.86769
38.86624
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38.8613
38.86005
38.85887
38.85804
38.85755
38.8574
38.85744
38.85745
38.8575
38.85763
Latitude

FIG. 8